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(54) **BUSH COMPONENT FORCE DETECTION DEVICE**

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G01L 5/00 (2006.01)

(52) **U.S. Cl.**

CPC **G01M 17/04** (2013.01); **G01L 5/0057** (2013.01)

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CPC G01L 5/0004; G01L 3/108; G01L 5/0057; G01L 5/0009; G01M 17/04

USPC 73/117.03, 862.338, 862.044, 862.045
See application file for complete search history.

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(57) **ABSTRACT**

A bush component force detection device detects a component force acting on a bush which is press-fitted into a hole provided in a frame of a vehicle. The bush component force detection device includes: a cylinder which is inserted into the hole with predetermined space therefrom and has strain gauges; elastically deformable outer-side projections that extend in an axial direction of the cylinder and project radially outward from an outer surface of the cylinder; and elastically deformable inner-side projections that extend in an axial direction of the cylinder and project radially inward from an inner surface of the cylinder.

4 Claims, 6 Drawing Sheets

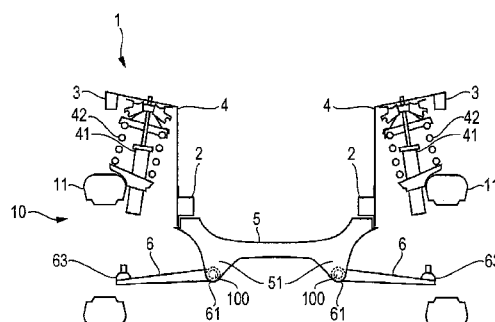


FIG. 1

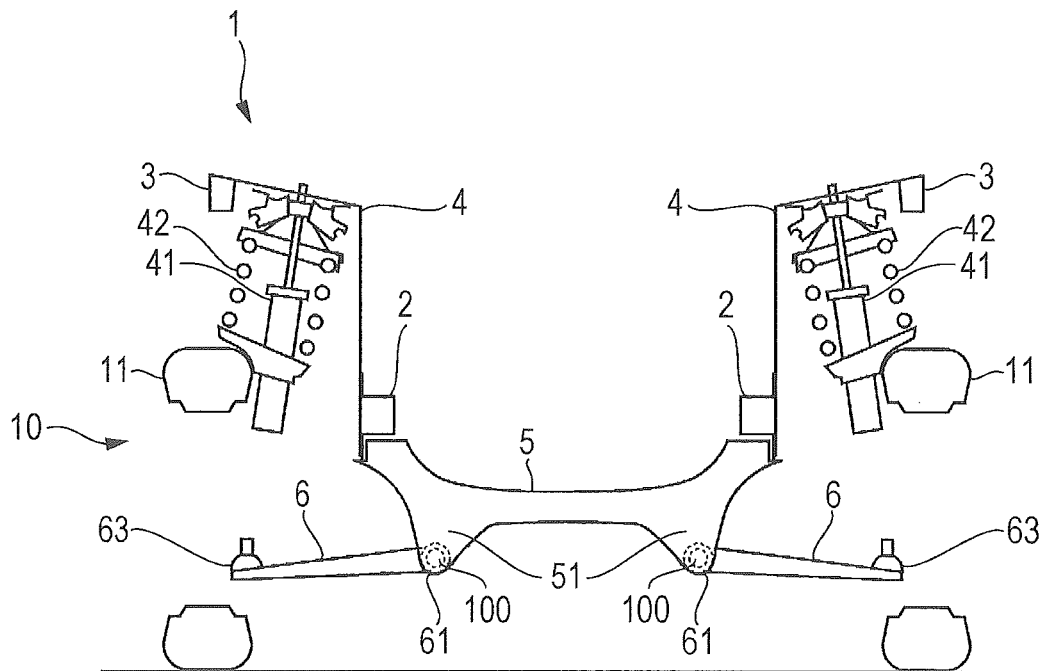


FIG. 2

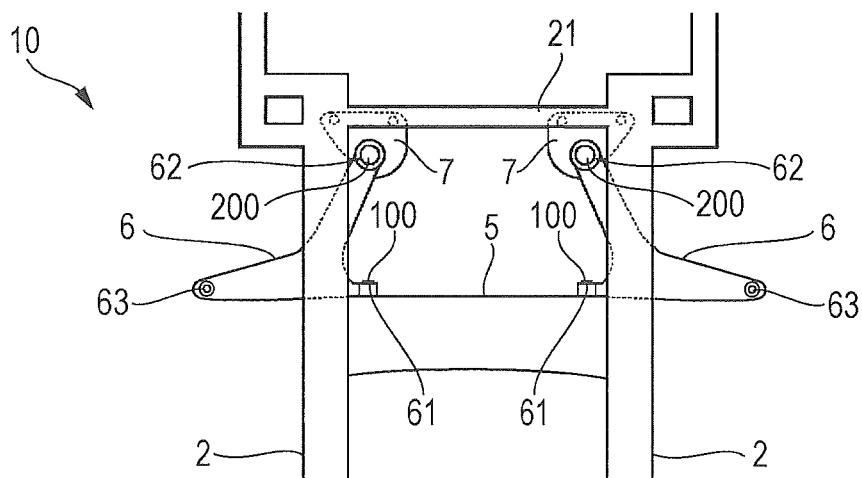


FIG. 3A

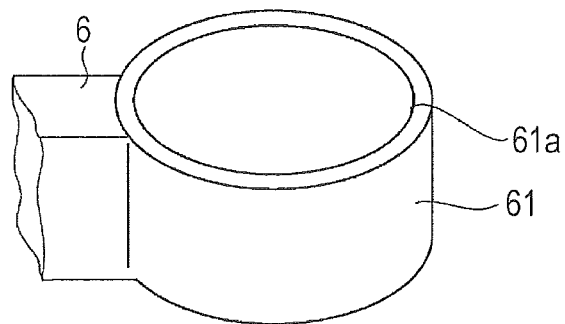


FIG. 3B

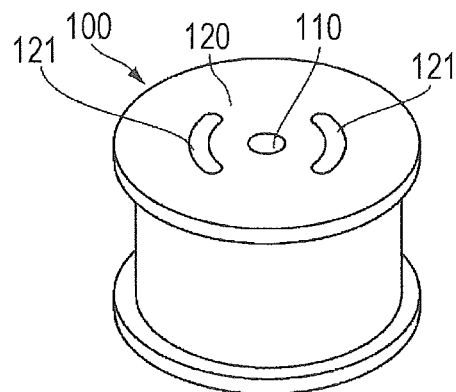


FIG. 3C

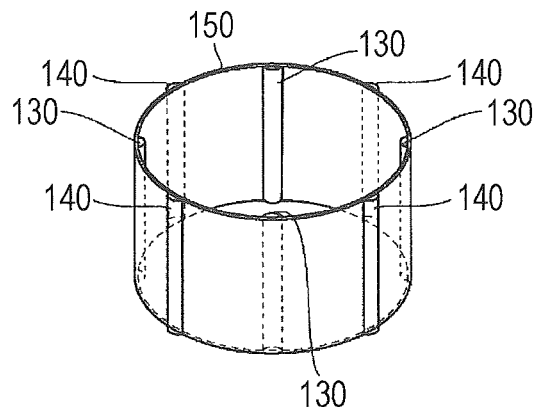


FIG. 3D

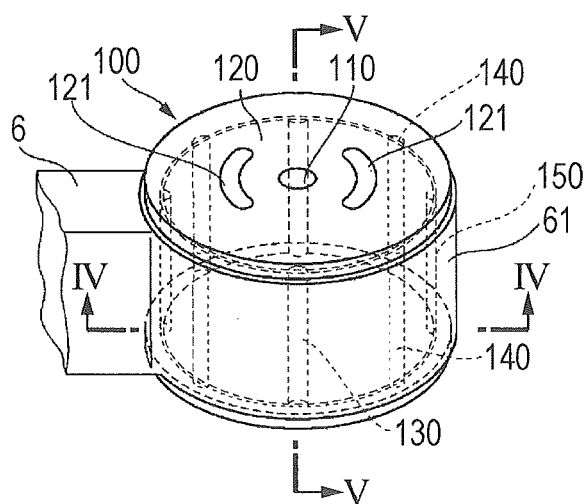


FIG. 4

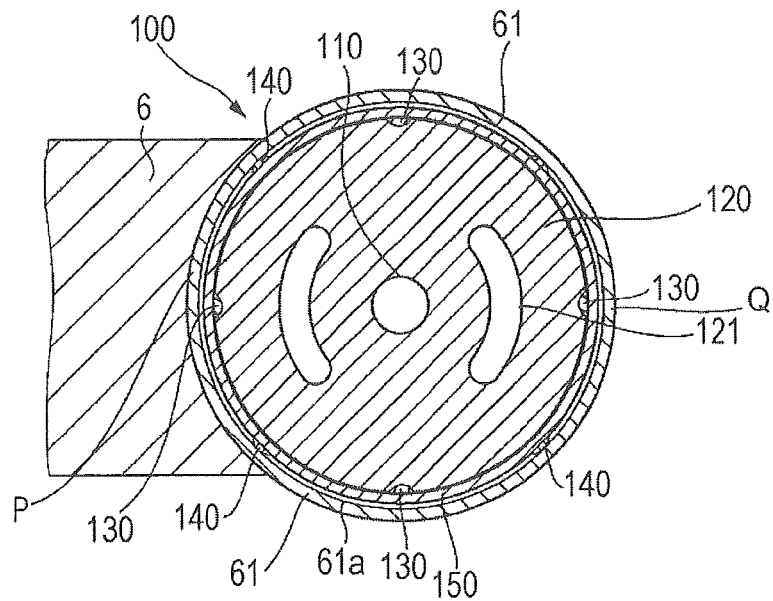


FIG. 5

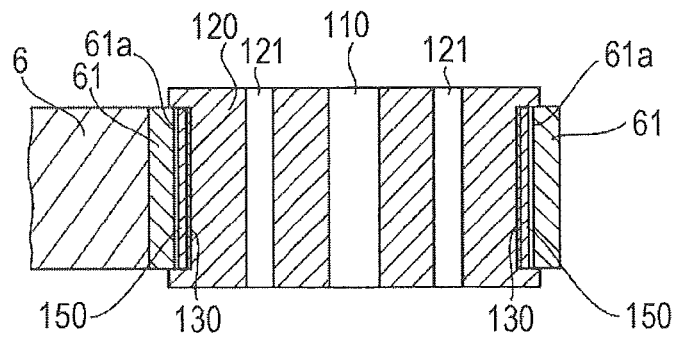


FIG. 6

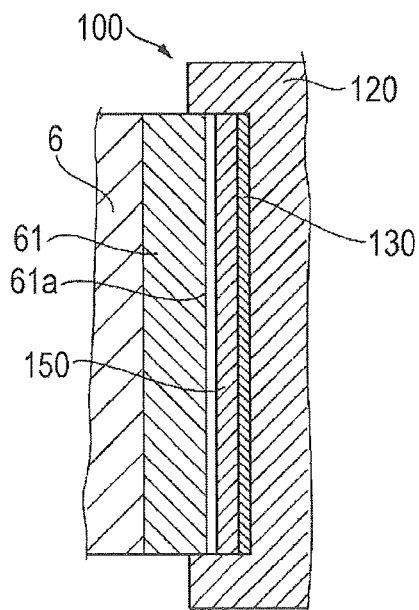


FIG. 7

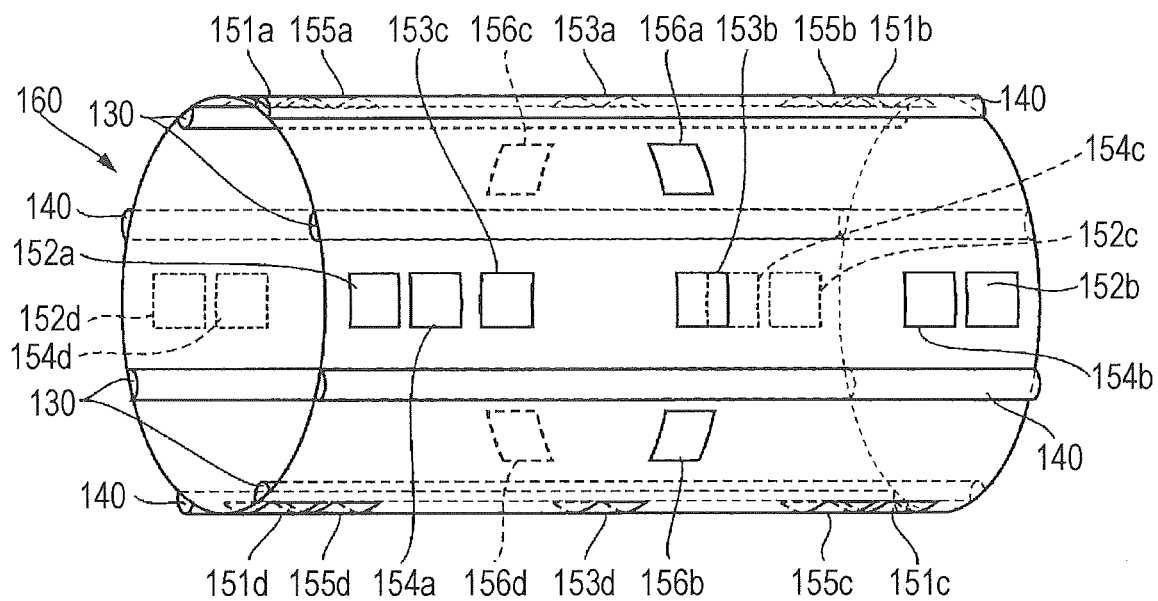


FIG. 8A

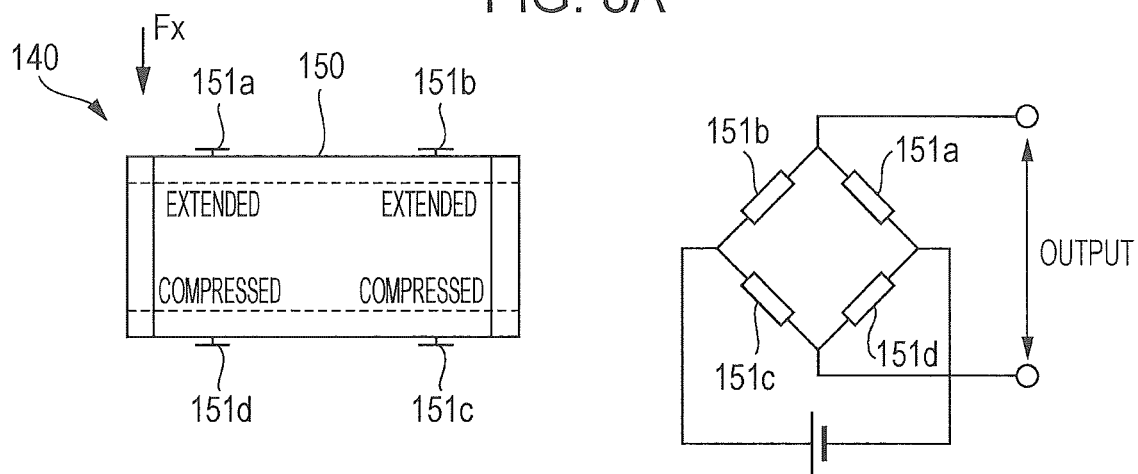


FIG. 8B

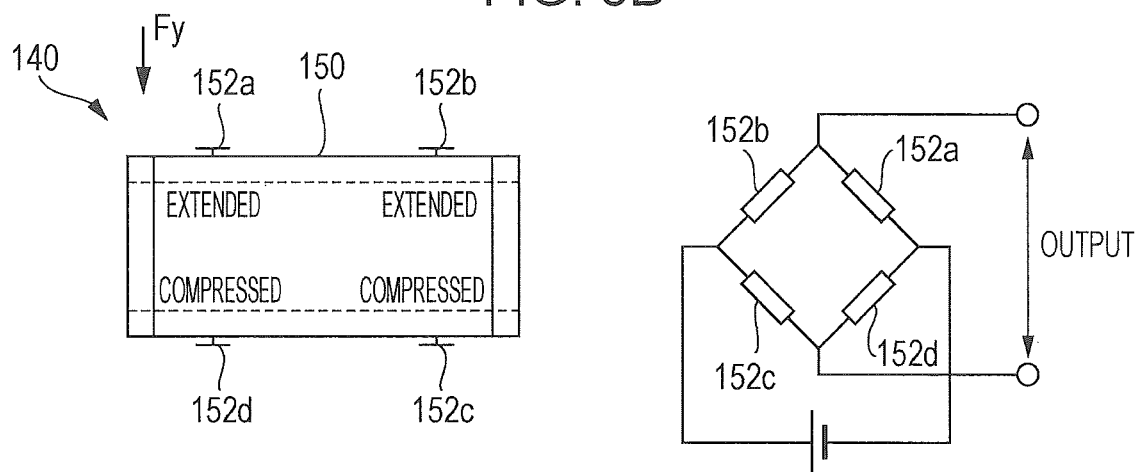


FIG. 8C

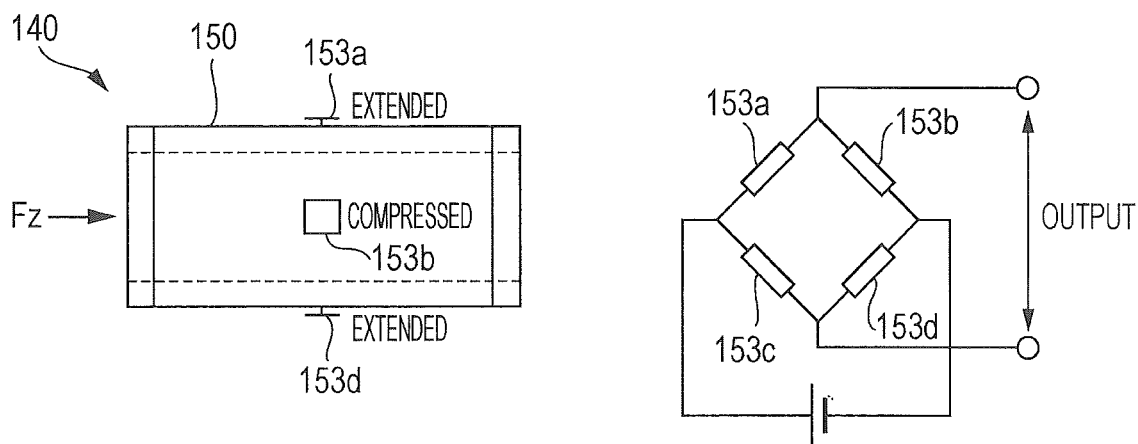


FIG. 9A

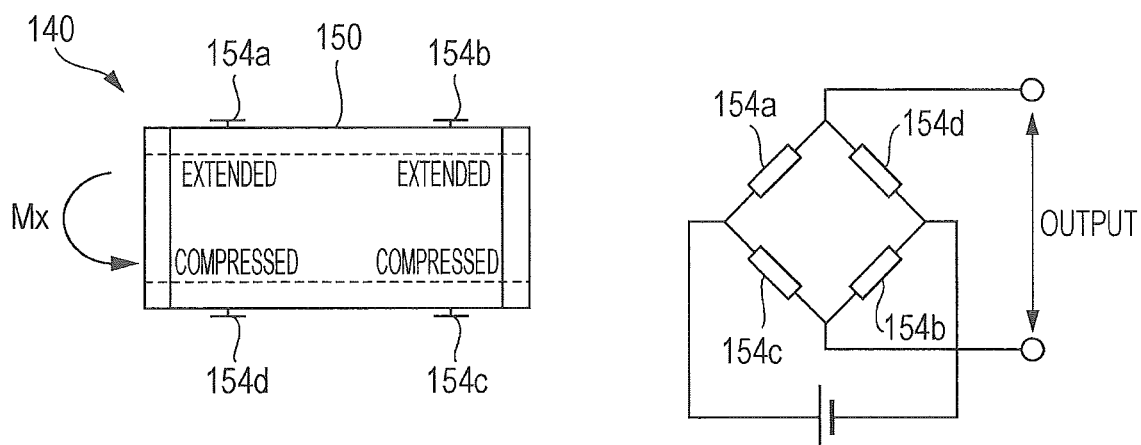


FIG. 9B

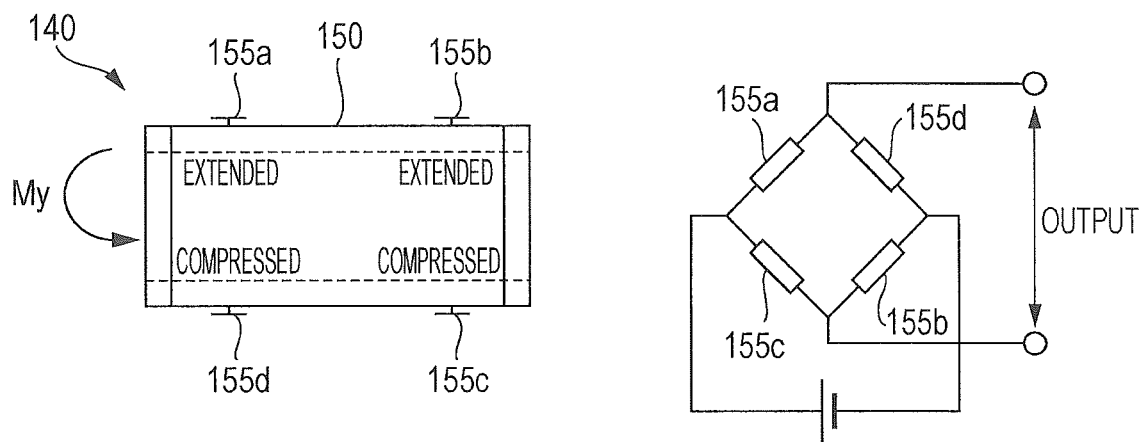
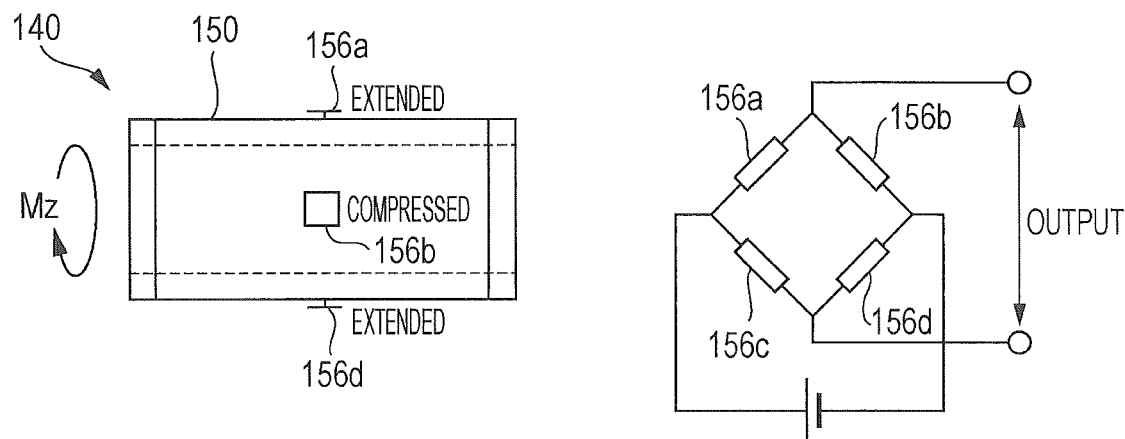


FIG. 9C



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BUSH COMPONENT FORCE DETECTION DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority from Japanese Patent Application No. 2013-098596 filed on May 8, 2013, the entire contents of which are hereby incorporated by reference.

BACKGROUND

1. Technical Field

The present invention relates to a bush component force detection device that detects a component force acting on a bush which is provided in a connecting portion of a structural member of a vehicle.

2. Related Art

The suspension of a vehicle has an effect on riding comfort and driving stability of the vehicle, and so component forces of the suspension are measured to evaluate the riding comfort and driving stability of the vehicle. A vehicle is designed based on the evaluation of the riding comfort and driving stability of the vehicle. Therefore, the riding comfort and driving stability of a vehicle can be improved by accurately measuring dynamic change in each component force in portions of the suspension.

Various methods have been proposed to detect changes in component forces such as yaw, pitch, and roll which act on the portions of the suspension mechanism. For example, Japanese Unexamined Patent Application Publication No. 2011-85514 discloses a load measurement sensor which includes a plurality of strain gauges and is tightly fixed to a rod-like body such as a damper in the suspension mechanism of a vehicle.

Here, shafts, which serve as connecting portions between the frame of the vehicle and an arm member, are base points for allowing the arm member to be moved, and thus for the design and adjustment of the suspension mechanism, it is necessary to detect component forces in the connecting portions between the frame and the arm member with high accuracy.

However, even if a sensor is mounted on a damper, an arm member or the like as described above for measuring the behavior of each of the portions of the suspension, the behavior of each shaft (movable connecting portion of each member) may not be measured accurately. That is, in order to measure the behavior of each shaft of the suspension, calculation is performed based on a result of measurement made by a sensor which is mounted on an arm or a damper connected to the shaft to be measured, and thus the calculation gives only a predicted value. Particularly, when an elastic body is used for a bearing of the suspension, the distribution of the force acting on the bush varies depending on the position and the quality of material of the mounting member of the bush, and thus it is difficult to measure the distribution of the force acting on the bush accurately by the method of calculation as mentioned above.

SUMMARY OF THE INVENTION

The present invention has been designed in consideration of the circumstances described above, and an object thereof is to provide a bush component force detection device capable of detecting the distribution of component force in each bearing in a suspension mechanism of a vehicle with high accuracy.

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A first aspect of the present invention provides a bush component force detection device that detects a component force acting on a bush which is press-fitted into a hole provided in a frame of a vehicle. The bush component force detection device includes: a cylinder which is inserted into the hole with predetermined space therefrom and has strain gauges; elastically deformable outer-side projections that extend in an axial direction of the cylinder and project radially outward from an outer surface of the cylinder; and elastically deformable inner-side projection that extend in an axial direction of the cylinder and project radially inward from an inner surface of the cylinder.

Each of the outer-side projections may be disposed at an interval from adjacent outer-side projections in a circumferential direction of the cylinder, and each of the inner-side projections may be disposed at an interval from adjacent inner-side projections in the circumferential direction of the cylinder.

The outer-side projections and the inner-side projections are alternately disposed in the circumferential direction of the cylinder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic front view of a suspension device of a vehicle according to an implementation of the present invention;

FIG. 2 is a schematic plan view from above of the suspension device of FIG. 1;

FIGS. 3A to 3D are perspective views of a mount of a front bush, the front bush, a sensing unit, and the end of a lower arm, respectively, of the present invention;

FIG. 4 is a cross-sectional view taken along IV-IV of FIG. 3D;

FIG. 5 is a cross-sectional view taken along V-V of FIG. 3D;

FIG. 6 is an enlarged schematic cross-sectional view of part of FIG. 5;

FIG. 7 is a schematic perspective view of a sensing unit of the implementation;

FIGS. 8A to 8C are diagrams each illustrating a configuration of a bridge circuit of a force detection system in a six component force detection device; and

FIGS. 9A to 9C are diagrams each illustrating a configuration of a bridge circuit of a moment detection system in the six component force detection device.

DETAILED DESCRIPTION

FIGS. 1 to 9 illustrate an implementation of the present invention.

As illustrated in FIGS. 1 and 2, a vehicle body 1 of a vehicle equipped with a bush component force detection device of the implementation includes side members 2, upper members 3, strut towers 4, a cross member 5, and a suspension device 10.

Each of the side members 2 is a structural member that extends from a toe board (not illustrated) in a fore-and-aft direction of the vehicle, the toe board serving as a partition wall at the front of the cabin. The side members 2 are provided as a pair on the right and left sides of the engine compartment of the vehicle. The rear ends of the side members 2 on the right and left are connected to each other by a connecting member 21.

The upper members 3 are provided over the right and left side members 2, respectively in a direction outwardly of the vehicle. Each of the upper members 3 is a structural member

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that extends from the partition wall at the front of the cabin along the right and left edges of an engine hood in a fore-and-aft direction of the vehicle.

The strut towers **4** are provided between the outer ends of the side members **2** in a vehicle width direction and the inner ends of the upper members **3** in a vehicle width direction. The upper ends of the shock absorbers **41** described below are fixed to the strut towers **4**.

The cross member **5** is a structural member that extends in a vehicle width direction and the both ends thereof are secured to the lower surfaces of the right and left side members **2** using a bolt or the like. Under the cross member **5**, brackets **51** project downward which are connected to the respective lower arms **6** described below.

The suspension device **10** includes shock absorbers **41**, lower arms **6**, and support plates **7**.

The shock absorbers **41** are each a hydraulic shock absorber that has a coil spring **42** on the outer circumferential surface. The upper end of each shock absorbers **41** is rotatably mounted on corresponding one of the strut towers **4** and the lower end thereof is secured and fixed to the upper end of a front wheel suspension member (not illustrated) which rotatably supports a front wheel **11**.

The lower arms **6** are suspension arms that are provided as a pair on the right and left sides in a vehicle width direction to support the lower ends of front wheel suspension members. Front bush mounts **61** are provided at the front side in the vehicular fore-and-aft direction of the inner ends of the right and left lower arms **6** in a vehicle width direction. Rear bush mounts **62** are provided at the rear side in the vehicular fore-and-aft direction of the inner ends of the right and left lower arms **6** in a vehicle width direction. Ball joints **63** are provided at the outer ends of the vehicle in a vehicle width direction.

As illustrated in FIG. 3A, each of the front bush mounts **61** is provided at the end of a corresponding lower arm **6**, and a cylindrically shaped hole **61a** having a central axis extending along the rocking central axis of the lower arm **6** is formed in the front bush mount **61**. A front bush **100**, which is press-fitted into the below-described sensing unit **150**, is press-fitted into the hole **61a**.

As illustrated in FIG. 3B, the front bush **100** is a cylindrically-shaped rubber bush for vibration isolation, and includes an inner cylinder **110**, and a rubber **120**. In the rubber **120**, bores **121** are formed as a pair on the right and left. The bores **121** are openings through in the axial direction of the inner cylinder **110**. Each of the bores **121** is formed in an arc-shape in a plan view centered about the inner cylinder **110**, and has different coefficients of elasticity in a radial direction (the x-axis direction) of the rubber **120** and in another radial direction (the y-axis direction) perpendicular to the x-axis.

The sensing unit **150** is included in the below-described front bush component force detection device **160**, and is formed in a cylindrical shape as illustrated in FIG. 3C. A plurality of inner-side projections **130** is provided on the inner circumferential surface of the sensing unit **150**, and a plurality of outer-side projections **140** is provided on the outer circumferential surface thereof. The inner-side projections **130** are elastic members that are formed along the axial direction of the sensing unit **150** and project radially inward from the inner circumferential surface of the sensing unit **150**. The outer-side projections **140** are elastic members that are formed along the axial direction of the sensing unit **150** and project radially outward from the outer circumferential surface of the sensing unit **150**. The inner-side projections **130** and the outer-side projections **140** are alternately disposed at regular intervals in the circumferential direction of the sens-

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ing unit **150**. In the present implementation, the number of provided inner-side projections **130** and outer-side projections **140** are four each.

As illustrated in FIG. 3D, the front bush **100** is press-fitted into the sensing unit **150**, and the sensing unit **150**, into which the front bush **100** is press-fitted, is press-fitted into the hole **61a**. That is, the front bush **100** is installed such that the sensing unit **150** is disposed so as to be interposed between the outer circumferential surface of the front bush **100** and the inner circumferential surface of the hole **61a** as illustrated in FIGS. 4 to 6. The front bush **100** is retained on the inner circumferential surface of the sensing unit **150** by radially outward pressure from the front bush **100**, and the sensing unit **150**, into which the front bush **100** is press-fitted, is retained on the inner circumferential surface of the hole **61a**.

Each of the rear bush mounts **62** is a portion into which the rear bush **200** is press-fitted and fixed, and specifically is a cylindrically shaped hole having a central axis extending along the rocking central axis of the lower arm **6** in the vehicular fore-and-aft direction. The rear bush **200** is a rubber bush for vibration isolation in a similar configuration to that of the front bush **100**, and includes an inner cylinder and a rubber which has holes. The lower arm **6** is connected to a corresponding, support plate **7** by a bolt which is inserted into the inner cylinder of the rear bush **200** which is press-fitted into the rear bush mount **62**.

The support plate **7** is a tabular member for supporting a lower portion of the lower arm **6** and is connected to a corresponding rear bush **200** by a bolt and secured to a portion near the rear end of the side member **2** by a bolt or the like, the rear bush **200** being press-fitted into the rear bush mount **62** of the lower arm **6** on each side.

Next, a front bush component force detection device **160** for detecting a component force will be described with reference to FIGS. 4 to 9, the component force acting on the front bush **100**.

The front bush component force detection device **160** detects six component forces acting on the front bush **100** which connects the lower arm **6** and the cross member **5**. The front bush component force detection device **160** includes a sensing unit **150**, a plurality of strain gauges provided in the sensing unit **150**, and a bridge circuit including the strain gauges, and further includes Fx detection system, Fy detection system, Fz detection system, Mx detection system, My detection system, and Mz detection system.

As illustrated in FIG. 7, the strain gauges are attached in rows along the axial direction of the sensing unit **150** between the inner-side projections **130** on the inner circumferential surface and the outer-side projections **140** on the outer circumferential surface of the sensing unit **150**. Therefore, as illustrated in FIGS. 4 to 6, the strain gauges attached on the outer circumferential surface of the sensing unit **150** are not in contact with the inner circumferential surface of the hole **61a** because the outer circumferential surface of the sensing unit **150** and the inner circumferential surface of the hole **61a** are spaced apart by the outer-side projections **140**. It should be noted that the strain gauges are formed in multiple rows, and in the present implementation, the strain gauges are attached on the sensing unit **150** in eight rows.

Fx detection system detects a force Fx acting on the sensing unit **150** in a radial direction (hereinafter x-axis direction). Fy detection system detects a force Fy acting on the sensing unit **150** in a radial direction (hereinafter y-axis direction) perpendicular to the x-axis direction. Fz detection system detects a force Fz acting on the sensing unit **150** in an axial direction (hereinafter z-axis direction). Mx detection system detects a moment Mx acting on the sensing unit **150** around the x-axis.

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My detection system detects a moment M_y acting on the sensing unit 150 around the y-axis. M_z detection system detects a moment M_z acting on the sensing unit 150 around the z-axis.

Each of F_x detection system, F_y detection system, F_z detection system, M_x detection system, M_y detection system, and M_z detection system has a bridge circuit including four strain gauges.

F_x detection system has strain gauges 151a, 151b, 151c, and 151d. The strain gauges 151a to 151d are strain gauges for a single axis, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the central axis direction of the sensing unit 150.

As illustrated in FIG. 8A, in the bridge circuit of F_x detection system, the strain gauges 151a to 151d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 151b and 151c and a point between the strain gauges 151a and 151d, thereby generating a potential difference across a point between the strain gauges 151a and 151b and a point between strain gauges 151c and 151d.

As illustrated in FIG. 7, F_y detection system has strain gauges 152a, 152b, 152c, and 152d. The strain gauges 152a to 152d are strain gauges for a single axis, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the central axis direction of the sensing unit 150 and the positions of the strain gauges 152a to 152d are 90 degrees shifted in phase around the central axis of the sensing unit 150 with respect to the attachment positions of the strain gauges 151a to 151d.

As illustrated in FIG. 8B, in the bridge circuit of F_y detection system, the strain gauges 152a to 152d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 152b, 152c and a point between the strain gauges 152a, 152d, thereby generating a potential difference across a point between the strain gauges 152a, 152b and a point between strain gauges 152c, 152d.

As illustrated in FIG. 7, F_z detection system has strain gauges 153a, 153b, 153c, and 153d. The strain gauges 153a to 153d are strain gauges for a single axis, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the central axis direction of the sensing unit 150. The strain gauge 153a is disposed at the midpoint between the strain gauges 151a and 151b, and the strain gauges 153b to 153d are disposed at the positions 90 degrees, 180 degrees, and 270 degrees shifted in phase, respectively around the central axis of the sensing unit 150 with respect to the strain gauge 153a.

As illustrated in FIG. 8C, in the bridge circuit of F_z detection system, the strain gauges 153a to 153d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 153a, 153c and a point between the strain gauges 153b, 153d, thereby generating a potential difference across a point between the strain gauges 153a, 153b and a point between strain gauges 153c, 153d.

As illustrated in FIG. 7, M_x detection system has strain gauges 154a, 154b, 154c, and 154d. The strain gauges 154a to 154d are strain gauges for a single axis, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the central axis direction of the sensing unit 150. The strain gauges 154a to

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154d are disposed adjacent to the strain gauges 152a to 152d, respectively in the central axis direction of the sensing unit 150.

As illustrated in FIG. 9A, in the bridge circuit of M_x detection system, the strain gauges 154a to 154d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 154a, 154c and a point between the strain gauges 154b, 154d, thereby generating a potential difference across a point between the strain gauges 154a, 154b and a point between strain gauges 154c, 154d.

As illustrated in FIG. 7, M_y detection system has strain gauges 155a, 155b, 155c, and 155d. The strain gauges 155a to 155d are strain gauges for a single axis, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the central axis direction of the sensing unit 150. The strain gauges 155a to 155d are disposed adjacent to the strain gauges 151a to 151d, respectively in the central axis direction of the sensing unit 150.

As illustrated in FIG. 9B, in the bridge circuit of M_y detection system, the strain gauges 155a to 155d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 155a, 155c and a point between the strain gauges 155b and 155d, thereby generating a potential difference across a point between the strain gauges 155a and 155b and a point between strain gauges 155c and 155d.

As illustrated in FIG. 7, M_z detection system has strain gauges 156a, 156b, 156c, and 156d. The strain gauges 156a to 156d are shear strain gauges, and are attached on the outer circumferential surface of the sensing unit 150 so that the direction of detection is parallel to the circumferential direction of the sensing unit 150. The strain gauges 156a and 156b are disposed between the strain gauges 153a, 153b and between the strain gauges 153b and 153d, respectively. The strain gauges 156c and 156d are disposed symmetrically to the strain gauges 156a and 156b with respect to the central axis of the sensing unit 150.

As illustrated in FIG. 9C, in the bridge circuit of M_z detection system, the strain gauges 156a to 156d are sequentially connected in a loop, and the positive electrode and negative electrode of a power supply are respectively connected to a point between the strain gauges 156a and 156c and a point between the strain gauges 156b and 156d, thereby generating a potential difference across a point between the strain gauges 156a and 156b and a point between strain gauges 156c and 156d.

With such a configuration, the front bush component force detection device 160 detects the distribution of the component force acting on the front bush 100. For example, point P illustrated in FIG. 4 is the base end central portion of the front bush mount 61, and point Q is the very end of the front bush mount 61. In the present implementation, when the strain of point P portion is detected to be 1.1 mv/v, the strain of point Q portion is detected to be 1.36 mv/v, it can be observed that force F_x is displaced toward point P. In this manner, a force acting on the front bush 100 is detected for given positions, and thereby the shape and arrangement of the front bush mount 61, and displacement of force due to the size of the holes may be accurately observed.

The rear bush 200 is also provided with a rear bush detection device for detecting component forces acting on the rear bush 200. Similarly to the front bush component force detection device 160, the rear bush detection device includes an

inner ring, an outer ring, and a sensing unit. The rear bush detection device is capable of detecting component forces acting in radial directions (x-axis direction and y-axis direction), a component force acting in the axial direction (z-axis direction), a component force acting around the x-axis, a component force acting around the y-axis, and a component force acting around the z-axis, all the component forces acting on the rear bush **200**.

As described above, the inner-side projections **130** are provided on the inner circumferential surface of the sensing unit **150**, and the outer-side projections **140** and the strain gauges are provided on the outer circumferential surface of the sensing unit **150** which is provided between the front bush **100** and the hole **61a**, and thereby the distribution of the component forces acting on the front bush **100** may be directly and accurately detected. That is, the outer circumferential surface of the front bush **100**, which is press-fitted into the sensing unit **150**, has an increased contact surface with the inner circumferential surface of the sensing unit **150**, the increased being caused by the inner-side projections **130**, and thus deformation of the sensing unit **150** due to the pressure of the front bush **100** may be reduced to a minimum and the component forces may be accurately detected. In addition, a certain space is maintained between the outer circumferential surface of the sensing unit **150** and the inner circumferential surface of the hole **61a** by the outer-side projections **140**, which allows deformation of the sensing unit **150** and prevents a malfunction due to contact of the strain gauges with the inner circumferential surface of the hole **61a**. Thus, component forces may be accurately detected normally.

The plurality of inner-side projections **130** and outer-side projections **140** provided on the inner and outer circumferential surfaces of the sensing unit **150** are disposed at regular intervals, and thus non-uniform deformation of the sensing unit **150** may be prevented.

In the suspension device **10** for a vehicle in the present implementation, the lower arm **6** and the cross member **5** are connected via the front bush **100**, the lower arm **6** and the support plate **7** are connected via the rear bush **200**, and the front bush **100** and the rear bush **200** are provided with respective component force detection devices for detecting a component force acting of the bush. However, without being limited to this, a bush may be used for a bearing member of a connecting portion of other structural members, and the bush may be provided with a component force detection device which is similar to the front bush component force detection device **140** in the front bush **100**.

In the present implementation, a rubber bush is used for the front bush **100** and the rear bush **200**. However, without being limited to this, a bush using, for example, urethane may be adopted.

In the present implementation, a plurality of strain gauges is attached on the outer circumferential surface of the sensing unit **150**. However, without being limited to this, the plurality of strain gauges may be attached on the inner circumferential surface of the sensing unit **150**.

In the present implementation, the front bush component force detection device **160** is used to detect a component force acting on the front bush **100** mounted on the vehicle. How-

ever, without being limited to this, for example, a sensing unit may be provided independently, into which a bush is press-fitted, and a component force acting on the bush may be detected.

In the present implementation, the inner-side projections **130** and the outer-side projections **140** are provided at regular intervals in the circumferential direction of the sensing unit **150**. However, without being limited to this, the inner-side and outer-side projections **130**, **140** may be provided at irregular intervals. In this case, it is necessary to correct a measurement value in each bridge circuit.

In the present implementation, the outer-side projections **140** are provided on the outer circumferential surface of the sensing unit **150**. However, without being limited to this, the outer-side projections **140** may be provided on the inner circumferential surface of the hole **61a**.

In the present implementation, the number of provided inner-side projections **130** and outer-side projections **140** are four each. However, without being limited to this, the number may be greater than four or less than four, and the number of provided inner-side projections **130** may be greater than or less than the number of provided outer-side projections **140**. The strain gauges are attached on the sensing unit **150** in eight rows, however, the strain gauges may be attached in four rows or 16 rows.

The invention claimed is:

1. A bush component force detection device that detects a component force acting on a bush which is press-fitted into a hole provided in a frame of a vehicle, the bush component force detection device comprising:
 - a cylinder which is inserted into the hole with predetermined space therefrom and has strain gauges;
 - elastically deformable outer-side projections that extend in an axial direction of the cylinder and project radially outward from an outer surface of the cylinder; and
 - elastically deformable inner-side projections that extend in an axial direction of the cylinder and project radially inward from an inner surface of the cylinder,
 wherein the strain gauges are attached in rows along the axial direction of the cylinder between the inner-side projections and the outer-side projections.
2. The bush component force detection device according to claim 1, wherein
 - each of the outer-side projections is disposed at an interval from adjacent outer-side projections in a circumferential direction of the cylinder; and
 - each of the inner-side projections is disposed at an interval from adjacent inner-side projections in the circumferential direction of the cylinder.
3. The bush component force detection device according to claim 2, wherein the outer-side projections and the inner-side projections are alternately disposed in the circumferential direction of the cylinder.
4. The bush component force detection device according to claim 1, wherein the outer-side projections and the inner-side projections are alternately disposed in the circumferential direction of the cylinder.

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